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To: Mr. I. Corbu
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JARVIS/LONG POINT WIND COMPARISON

Report No. 91-290-K

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ABSTRACT

Wind data from a tower on the Long Point Penninsula are used to drive a hydraulic model of Lake Erie. Alternative sources of wind data are being explored. To this end, a statistical comparison between the wind direction and wind speed data measured at the Long Point and nearby Jarvis tower sites was undertaken. The objective of the comparison was to determine if the wind data measured at the two locations were similar. The analysis showed overall that wind direction and wind speed measured at the two sites were not closely correlated. When the data were grouped into wind direction categories, better correlations were found for northeasterly, southerly and southwesterly winds. It was concluded that development of a simple relationship between the two sites would not be feasible.

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1.0 INTRODUCTION

At the request of Operations Planning Facilities Department (OPFD), Power System Operations Division, the Environmental Physics and Chemistry Section (EPCS), Research Division, undertook a statistical comparison of the winds measured at Long Point, Ontario, and an inland site, Jarvis, Ontario. At present, tower-based wind measurements (ie, at the 34-m level) from a site at the end of the Long Point peninsula are being successfully used by OPFD in a real-time hydraulic modelling facility. The model requires hourly data on a reliable basis and is particularly sensitive to the wind input. The wind data OPFD obtain are from a tower operated by Atmospheric Environment Service (AES) of Environment Canada. The data are captured through the GOES satellite system at a time delay of approximately 40 minutes. With the time delay and having experienced reliability problems, OPFD were seeking alternatives to the present wind input to the model. Thus the purpose of this comparison was to determine if the Jarvis tower wind data could be used in place of the Long Point wind data as input to the hydraulic model.

The Jarvis tower site is located approximately 12 km inland from the lake Erie shoreline and 40 km directly north of the Long Point AES tower location. The distance between the Long Point site and the shoreline, along the N-S vector, is approximately 28 km. At the Jarvis tower, winds and temperature are measured at the 10- and 85-m levels.

In the process of undertaking the comparison study, it was discovered that the Ontario Ministry of the Environment (OME) also operate a meteorological tower at a location approximately mid-way along the Long Point peninsula. The OME tower is instrumented at the 10- and 85-m levels with wind and temperature sensors. The OME's and AES's Long Point wind measurement towers are essentially co-located (see Figure 1). As time was a consideration, it was decided to pursue the analysis using the OME data, as it was more readily available from archive than the AES data.

As required by OPFD the preliminary results of the comparison were relayed by September 30, 1991. The final results of the analysis are reported here. Section 2 describes the data and the statistical methods used in the comparison. Section 3 provides the results and discussion and Section 4 the conclusions and recommendations.

2.0 METHODS

Historical wind data measured at the Jarvis and Long Point sites were obtained. The time period of most interest to OPFD was the months of September to December, inclusive. Data for these months were obtained for a five year period (ie, 1986 to 1990). Due to poor data quality, only three years of data (ie, 1988 to 1990) were used in the comparison.

Table 1 offers descriptions of both the AES and OME Long Point tower sites as well as the Jarvis tower site. As shown in Figure 1 the coastline in this part of Lake Erie is

slightly irregular and points approximately 13 degrees north of east. Generally, the along shore winds are from the west and west-southwest and east and east-northeast. The across shore winds are from the north and north-northwest and south and south-southeast.

Table 1

Description of the Sites

Site	Location	Elevation (m)	Description
AES Long Point Tower	42 33' N 80 03' W	174	about 36 km off the shore; flat and surrounded by open water
OME Long Point Tower	42 35' N 80 23' W	174	about 30 km off the shore; flat and surrounded by open water
Jarvis Tower	42 53' N 80 05' W	215	about 12 km inland from the shore; flat agricultural land with urban build-ups a few km to the west

The 85-m level winds from the OME Long Point and the Jarvis towers were used in the comparison. The data were screened for obvious errors. Calm wind data, defined as below 2 m/s were not used in the analysis. The fraction of the data eliminated as being below the anemometer threshold (2 m/s) was 6% and 5% at the OME Long Point and the Jarvis towers, respectively. The remaining data were combined to produce a set of paired hourly values for the statistical analysis.

Several statistical analyses were applied to the data. The analysis for wind speed and wind direction were carried out independently. In addition to calculating statistics for all the data, analyses were also carried out by grouping the data into wind direction categories.

Using all the data, the mean, standard deviation and linear regression statistics were calculated. The regressions were calculated using zero intercepts to assess the one-to-one correspondence.

Using the paired data, differences were calculated by subtracting the Jarvis tower wind value from the Long Point values. The mean and standard deviations were determined and histograms of the paired differences plotted.

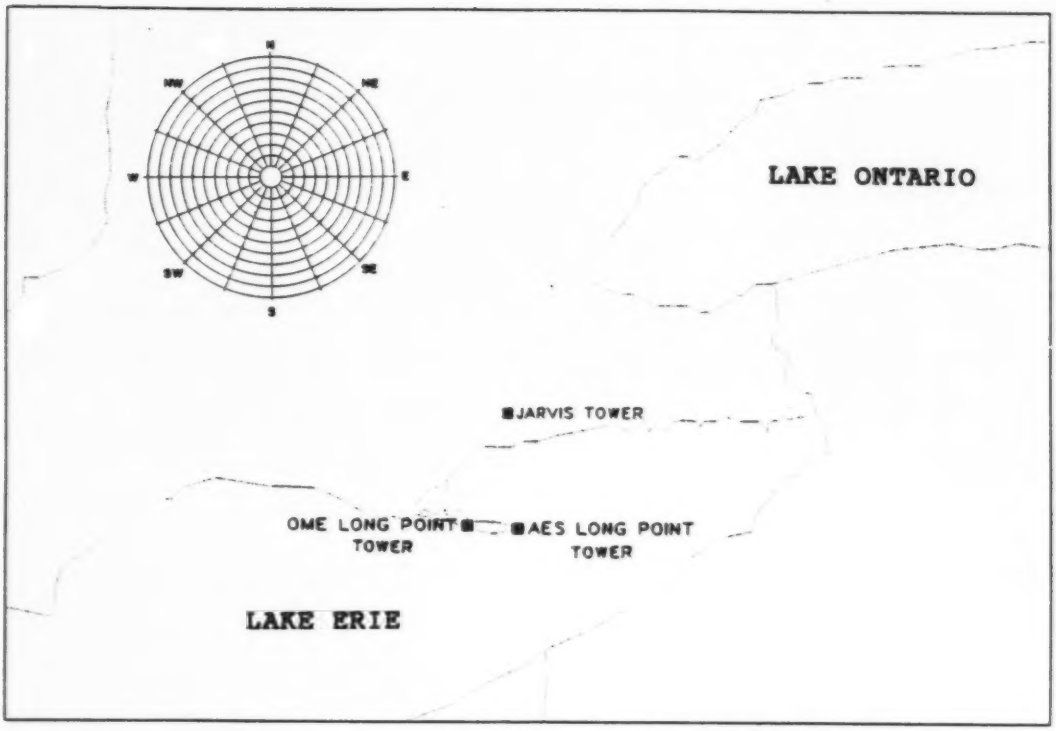


Figure 1: The Vicinity of the Long Point and Jarvis Towers

3.0 RESULTS AND DISCUSSION

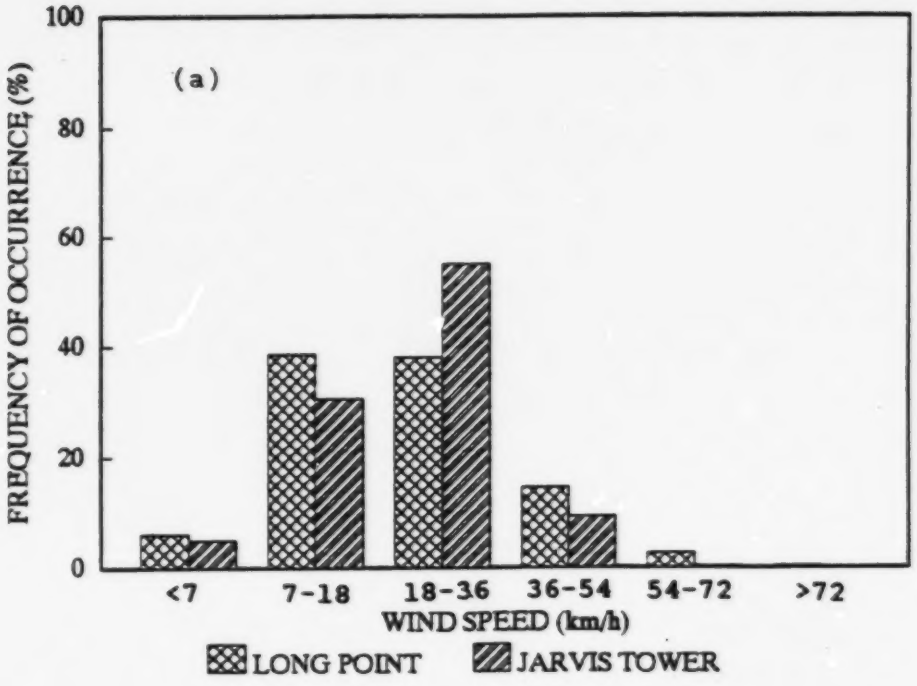
The mean and standard deviation calculated using the three years of wind observations are given in Table 2. Though the mean value of the winds measured at both towers is similar, the spread of the wind distribution is wider at Long Point than at Jarvis.

Table 2

Summary of the Statistics of the Wind Data

	OME Long Point Tower	OME Long Point Tower	Jarvis Tower	Jarvis Tower
	wind speed (km/h)	wind direction (degree)	wind speed (km/h)	wind direction (degree)
Mean	25.3	213.5	24.3	208.5
Standard Deviation	13.6	90.9	9.2	86.2

Figure 2 illustrates the characteristics of the data used in the analysis by showing the frequency of occurrence of the wind speed and wind direction at the two sites. The most common wind speed occurred in classes of 7 to 18 km/h (2 to 5 m/s) and 18 to 36 km/h (5 to 10 m/s). The most common wind direction was westerly. Over 60% of the winds were southwesterly, westerly and northwesterly during this period. From this simple comparison it is apparent that the Long Point site observes more frequently wind speeds above 36 km/h than the Jarvis site. Also, expected dissimilarity between the two sites, due to terrain effects, is evident in the wind speed and direction frequencies.



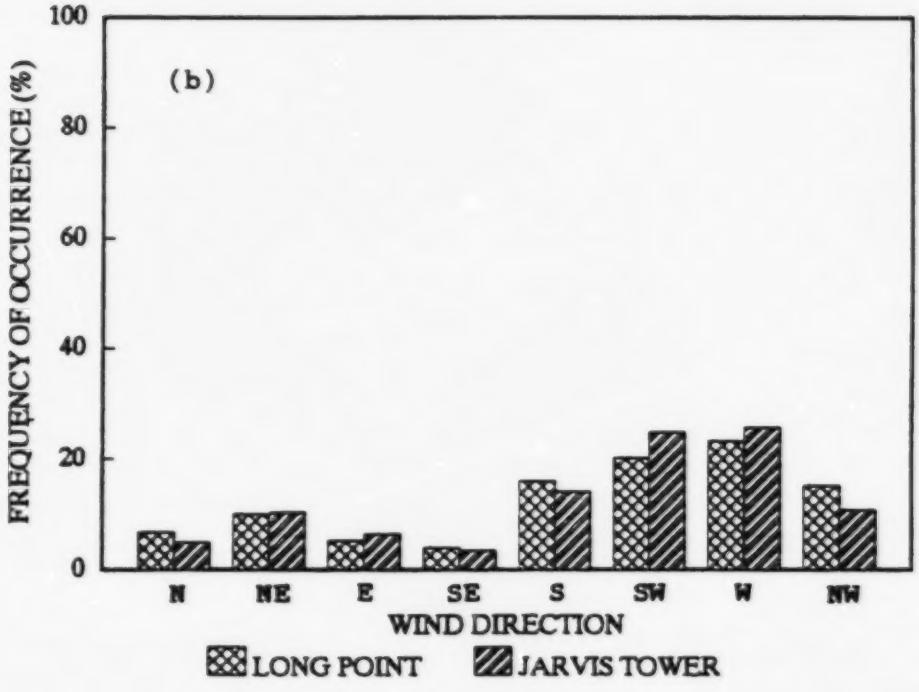


Figure 2: (a) Frequency of Occurrence of Wind Speed
(b) Frequency of Occurrence of Wind Direction

3.1 Representativeness of Wind Direction

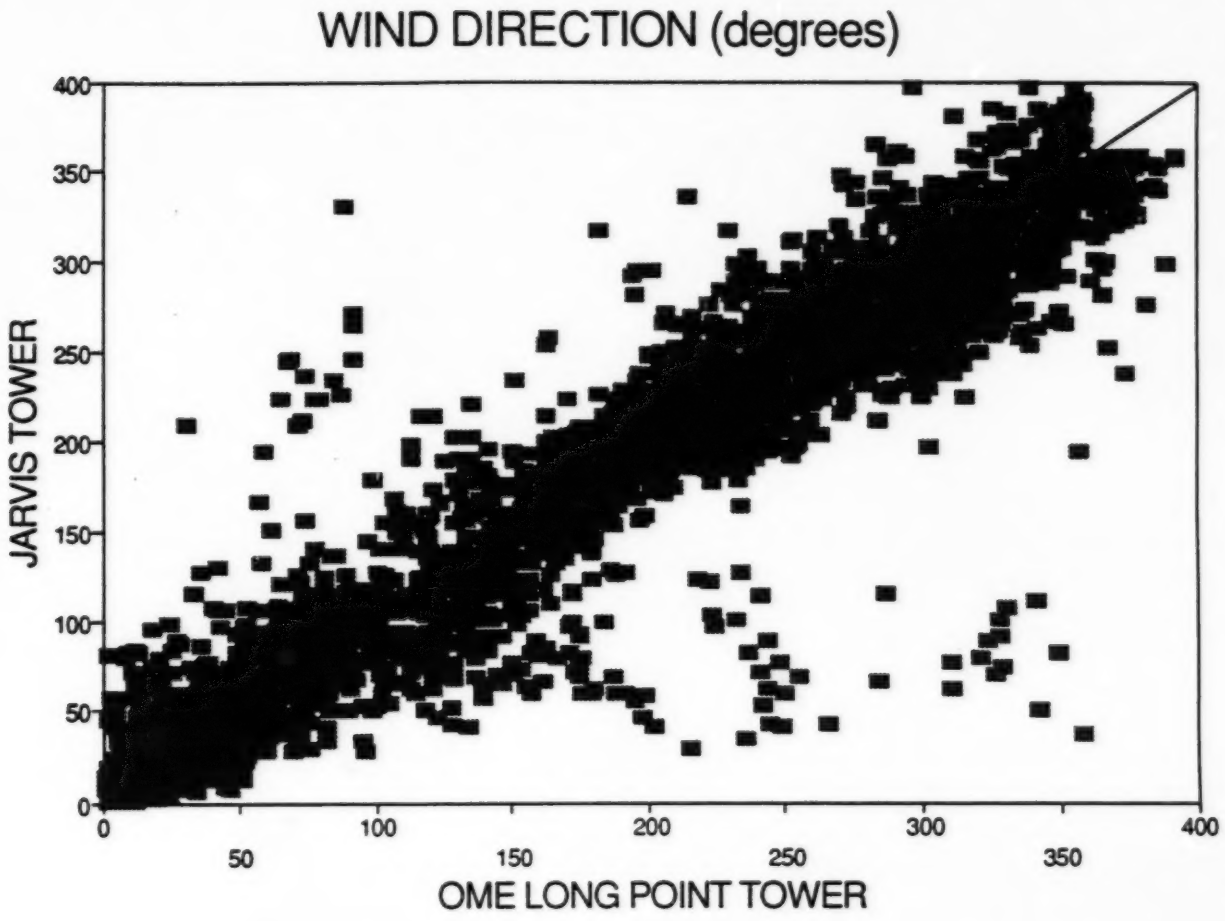
The scatter plot of wind direction using all the data is seen in Figure 3. The regression equation of the wind direction was determined as $y = 0.96\ x$. This indicates good correspondence for wind direction. The outlyers are the more interesting feature of this graph. They indicate the occurrence of mesoscale phenomena such as land and lake breeze, as well as terrain induced shear. For example, there are several cases where a NE wind is observed at the Jarvis tower and a N wind at the Long Point tower. As the wind moves off shore it speeds up as it encounters the lower friction water surface and thus turns. Another interesting feature of these data is the group of points seen in the upper right side of the graph. These points are during severe storm events (ie, wind speeds approximately 100 km/h) and the wind direction at Jarvis was observed to be westerly whereas at Long Point the winds were easterly. It is possible that the 180° difference was a result of approaching cyclonic cells, which may have passed south of the Long Point area during these events.

The histogram of paired differences of wind direction is shown in Figure 4. The mean and standard deviation are 4.6 and 25.2°, respectively. The mean of the paired differences indicates that the winds turned on average counterclockwise 4.6° as they moved from Long Point to Jarvis. This turning of the wind is expected since the surface roughness at Jarvis is higher than at Long Point (land vs lake surface).

The standard deviation of 25.2° indicates that the variation of wind direction between the two sites is considerable. Calculation of the frequency of occurrence of zero difference shows that 22.5% of the time the same wind direction occurs at both sites and 85.8% of the time the winds are within 45°. If a criterion of 90% agreement is used to accept the two wind data sets as comparable, then this criterion would not be met by the wind direction data.

The analysis of the wind direction was extended by grouping the data into eight generally used wind direction categories. Each group encompasses a 45° wind sector, representing winds from the north, northeast, east, southeast, south, southwest, west and northwest (also shown in Figure 1). Table 3 presents the mean and standard deviation of the paired differences of wind direction (in degrees) for each of these wind direction categories, as well as the frequency with which the same wind direction occurred at the two sites or was within a 45° sector. The histograms of the paired differences in wind direction for each of the wind direction groups are found in Appendix A.

When grouped, the wind direction data do not show as good a correspondence as was indicated by the regression analysis. The standard deviation of each of the categories varies between 20 and 33.8°. The frequency of occurrence of the same wind direction is in the range of 12.2 to 36.9%. The wind directions agree to within a 45° sector, better than 90% of the time, for the following three categories: NE, S and SW.



Regression Output:	
Constant	43.60288
Std Err of Y Est	48.78603
R Squared	0.681575
No. of Observations	7527
Degrees of Freedom	7525
X Coefficient(s)	0.777297
Std Err of Coef.	0.006125

Regression Output:	
Constant	0
Std Err of Y Est	51.83451
R Squared	0.640489
No. of Observations	7527
Degrees of Freedom	7526
X Coefficient(s)	0.952053
Std Err of Coef.	0.002615

Figure 3: Scatter Plot of Wind Direction (degrees)

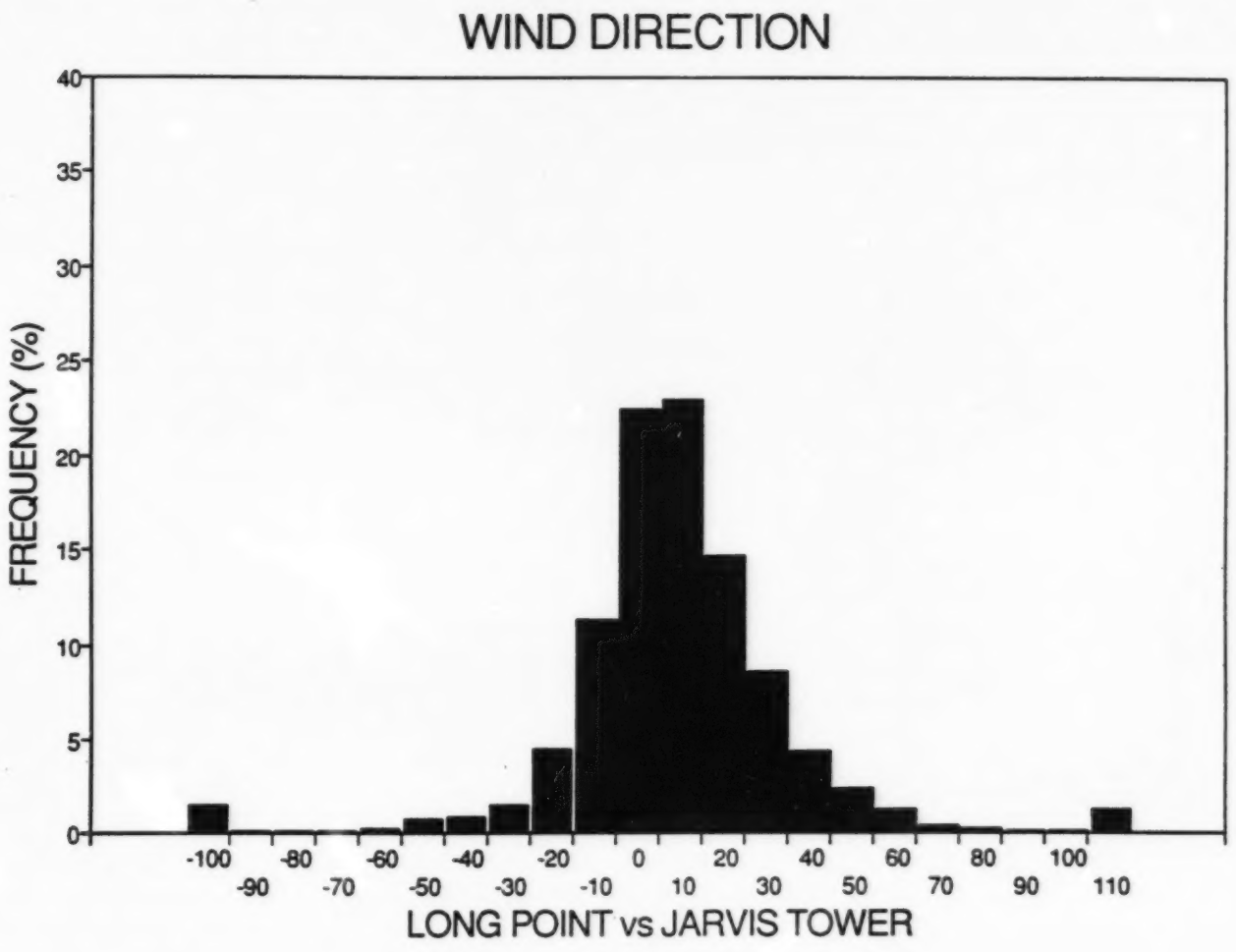


Figure 4: Histogram of Paired Differences for Wind Directions (the mean of the difference is 4.6 degrees and the standard deviation is 25.2 degree)

Table 3

Summary of the Mean and Standard Deviation of the Wind Direction Differences (degrees) and Frequency of Occurrence (%)

Wind Direction Category	Mean	Standard Deviation	% of time the same wind direction is observed	% of time the winds are within a 45° sector
N (337.5- 22.5)	**5.3**	**31.3**	**14.7**	**77.9**
NE (22.5- 67.5)	**-5.0**	**21.3**	**33.3**	**93.7**
E (67.5-112.5)	**-3.4**	**26.2**	**17.2**	**86.5**
SE (112.5-157.5)	**7.3**	**33.8**	**16.8**	**67.9**
S (157.5-202.5)	**-2.3**	**21.6**	**36.9**	**94.9**
SW (202.5-247.5)	**1.6**	**22.0**	**28.6**	**93.6**
W (247.5-292.5)	**9.6**	**20.0**	**14.1**	**88.2**
NW (292.5-337.5)	**18.0**	**30.6**	**12.2**	**73.4**

3.2 Representativeness of Wind Speed

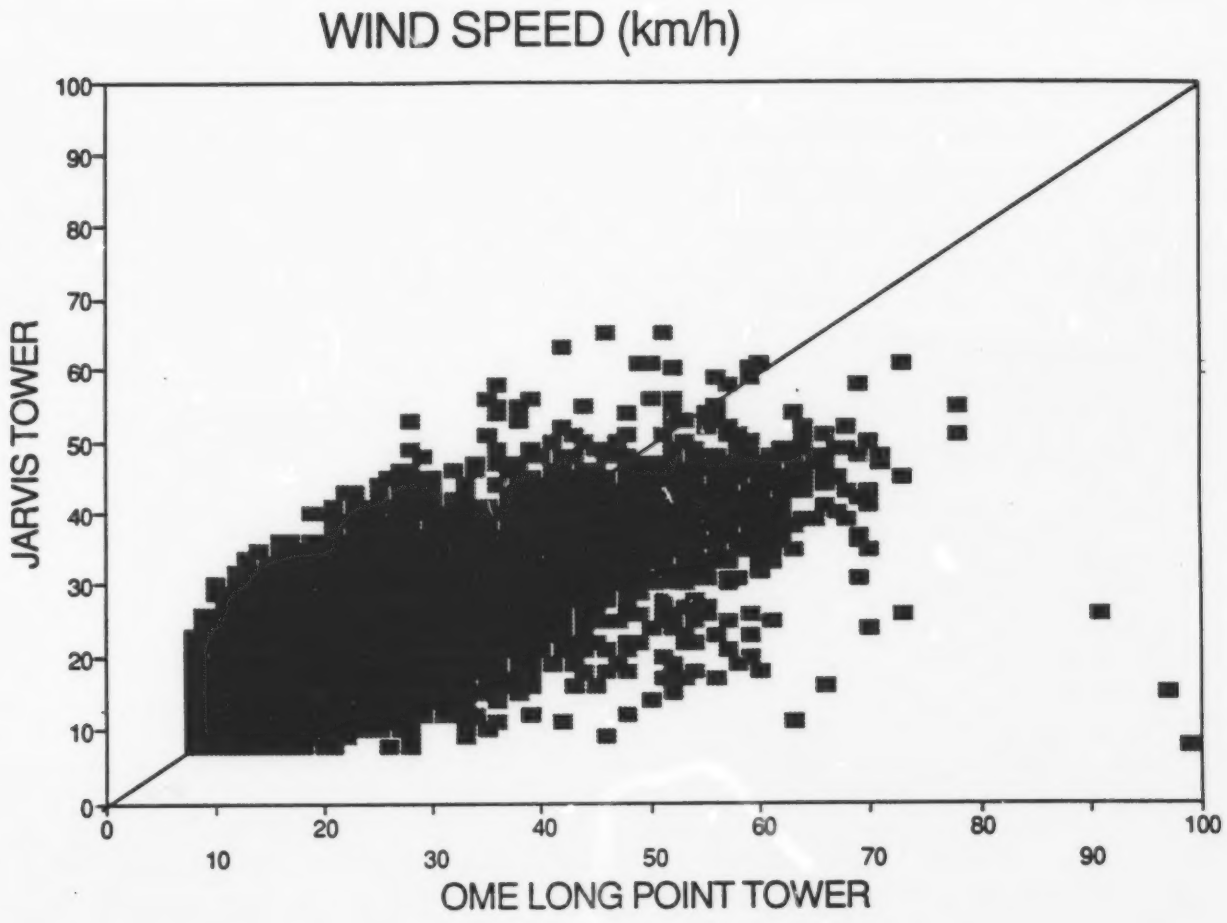
The scatter plot of wind speed measurements constructed using all the data is shown in Figure 5. The regression equation of wind speeds was determined as $y = 0.85 x$ if a zero intercept is specified. The best fit linear regression line was determined as $y = 0.46 x + 12.6$ if the requirement of a zero intercept is relaxed. As shown in Figure 5 the R squared and standard error of the Y estimate were slightly improved for the best fit line. The wind speed data are not as evenly distributed around the one-to-one correspondence line as the wind direction data. In general, the data show that the wind speeds are higher at Long Point than Jarvis. This result was also illustrated by Figure 2.

A large percentage of the time (see Figure 2) the winds move towards the Jarvis site from over the water. As the wind moves inland it will slow and turn counterclockwise. Therefore, overall, it would be expected that Long Point would see higher wind speeds than Jarvis. This is in fact the case.

The histogram of paired differences of wind speed is shown in Figure 6. The mean and standard deviation are 1.0 and 10.0 km/h, respectively. The mean difference is small, however, the standard deviation of 10 km/h is large enough to suggest that the sites are not similar. The hourly comparison showed that the same wind speed occurred only 8.9% of the time. Eighty percent of the time the wind speeds were within one standard deviation.

Table 4 displays the mean and standard deviation of the paired differences of wind speed (in km/h) for each of the wind direction categories, as well as the frequency with which the same wind speed occurred at the two sites or was within one standard deviation. The associated histograms and regression analyses for the grouped data are found in Appendix B. As can be seen, the standard deviation for each of the categories is lower than that of the overall winds, however the mean differences are in general larger. The frequency of occurrence of the same wind speed ranges from 6 to 18%; agreement to within one standard deviation ranged between 73 and 86%. Grouping the data does not suggest better agreement between the two sites. As might be expected, however, the data does show better agreement for Northerly winds.

Some consideration was given to the feasibility of applying a simple adjustment to the Jarvis wind speed such that it would represent Long Point winds. The linear regression statistics and the grouped data analyses suggest that a simple adjustment would not be viable.



Regression Output:

Constant	12.64343
Std Err of Y Est	6.753129
R Squared	0.462722
No. of Observations	7527
Degrees of Freedom	7525
X Coefficient(s)	0.461672
Std Err of Coef.	0.005735

Regression Output:

Constant	0
Std Err of Y Est	9.020376
R Squared	0.041271
No. of Observations	7527
Degrees of Freedom	7526
X Coefficient(s)	0.849871
Std Err of Coef.	0.003623

Figure 5: Scatter Plot of Wind Speed (km/h)

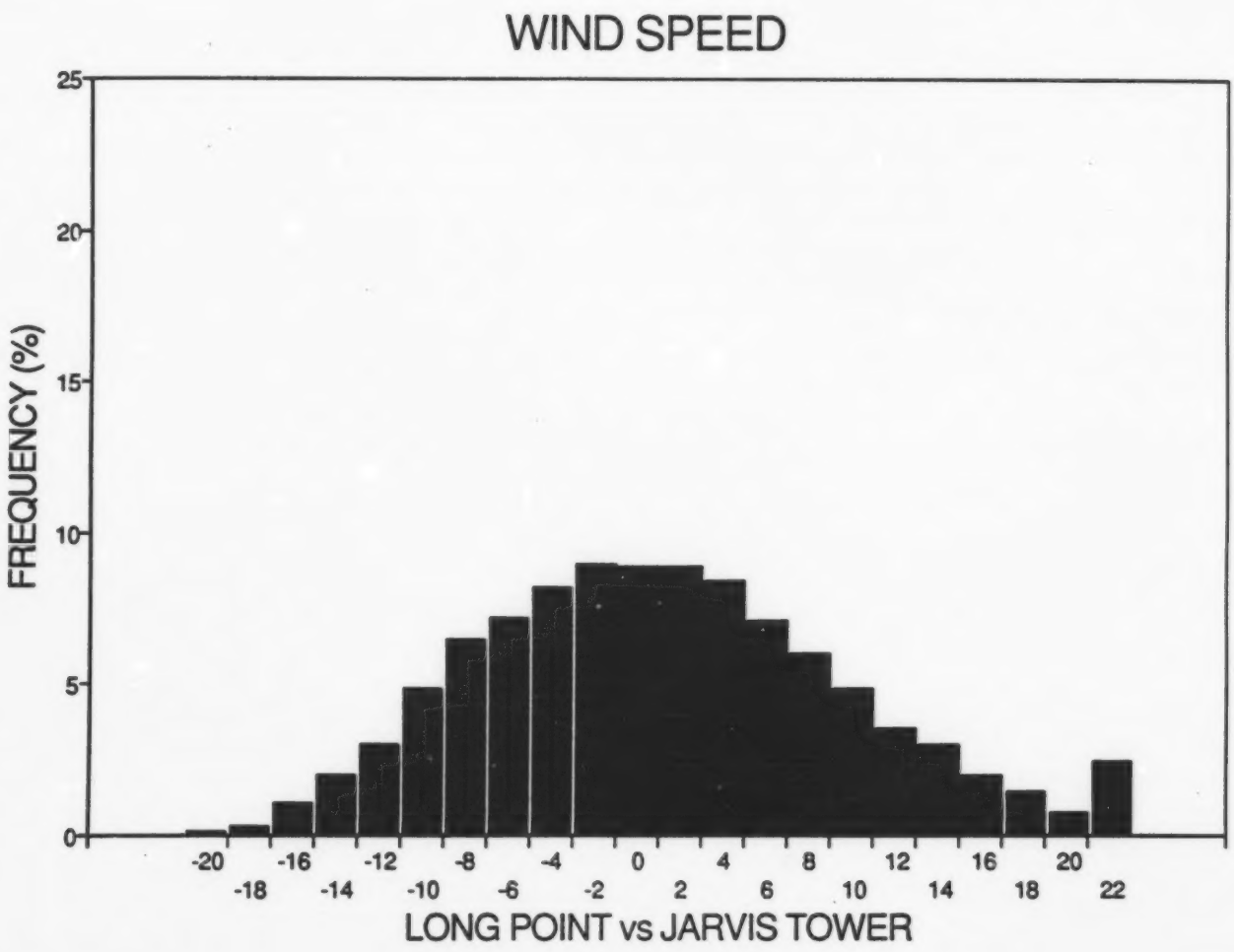


Figure 6: Histogram of Paired Differences for Wind Speeds (the mean of the difference is 1 km/h and the standard deviation is 10 km/h)

Table 4

Summary of the Mean and Standard Deviation of the Wind Speed Differences (km/h) and Frequency of Occurrence (%)

Wind Direction Category	Mean	Standard Deviation	% of time the same wind speed is observed	% of time the wind speeds are within one standard deviation
N (337.5- 22.5)	**0.3**	**5.9**	**17.3**	**86.0**
NE (22.5- 67.5)	**2.8**	**5.6**	**11.4**	**74.1**
E (67.5-112.5)	**-1.7**	**6.0**	**10.9**	**76.2**
SE (112.5-157.5)	**1.4**	**6.1**	**15.8**	**85.1**
S (157.5-202.5)	**5.0**	**6.4**	**9.3**	**80.4**
SW (202.5-247.5)	**7.9**	**9.4**	**6.4**	**77.3**
W (247.5-292.5)	**-3.5**	**8.0**	**6.4**	**78.3**
NW (292.5-337.5)	**-7.2**	**5.2**	**8.1**	**73.0**

4.0 CONCLUSIONS AND RECOMMENDATIONS

A statistical approach was used to compare wind data measured at the Jarvis meteorological tower with data measured on the Long Point Peninsula. The comparison highlighted some interesting features of the data, however it is apparent that the data from the Jarvis site could not be a direct substitute for the Long Point data. The statistics indicate that development of a simple relationship between the two sites would not be feasible.

The OPFD hydraulic model uses the square of wind speeds as input and therefore is particularly sensitive to high wind speeds. As well, the model has been found to be sensitive to wind direction (ie, ± 10°), especially for along-shore winds (Ken Lascivitta, personal communication). More liberal criteria than these were used in this analysis to assess the similarity of the winds. The wind directions were considered similar if the two measurements agreed to within a variance of one 22.5° sector, at least 90% of the time. For the overall winds, this criterion was not met at the Jarvis tower (the agreement was 85.8%). When the data were segregated by wind direction category, this criterion was met for northeasterly (93.7%), southerly (94.9%) and southwesterly (93.6%) winds. None of these belong to the along-shore wind category.

Wind speeds were assumed to be similar if the two measurements agreed to within one standard deviation, at least 90% of the time. The criterion was not met.

It is recommended that OPFD should use the OME Long Point wind data from the 85-m measurement level. Those data would be available in real-time and reliability should be improved, as the tower is accessible by land for maintenance.

ACKNOWLEDGEMENT

Our appreciation is extended to Mr P. Keily of the Ontario Ministry of the Environment for the prompt and efficient service with respect to wind data retrieval. We would also like to thank Mr. K. Lascivitta of OPFD and Mr. R. Gorski of Meteorology Section for their most helpful collaboration.

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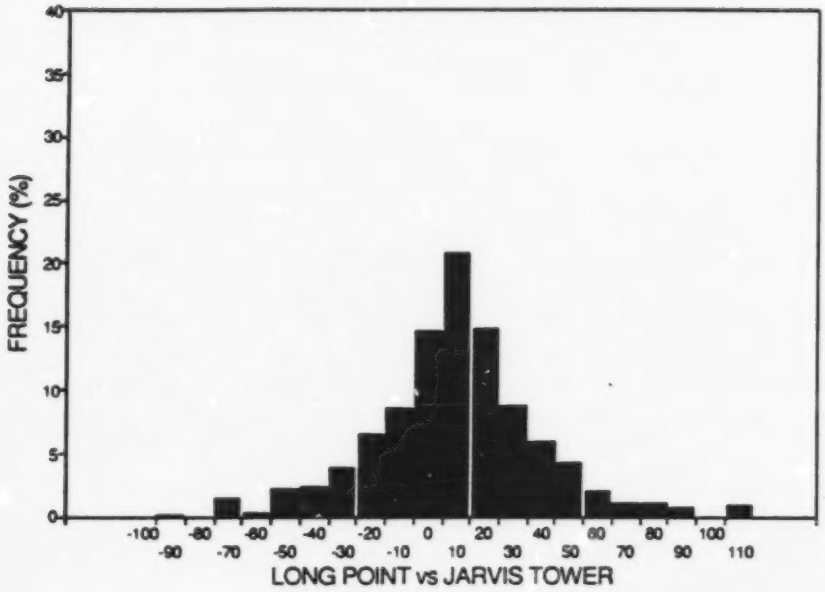
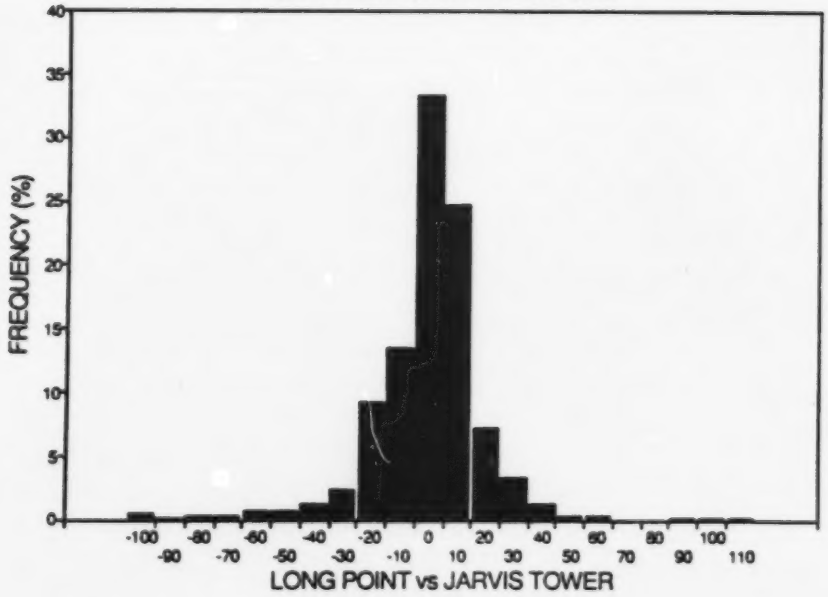
Appendix A

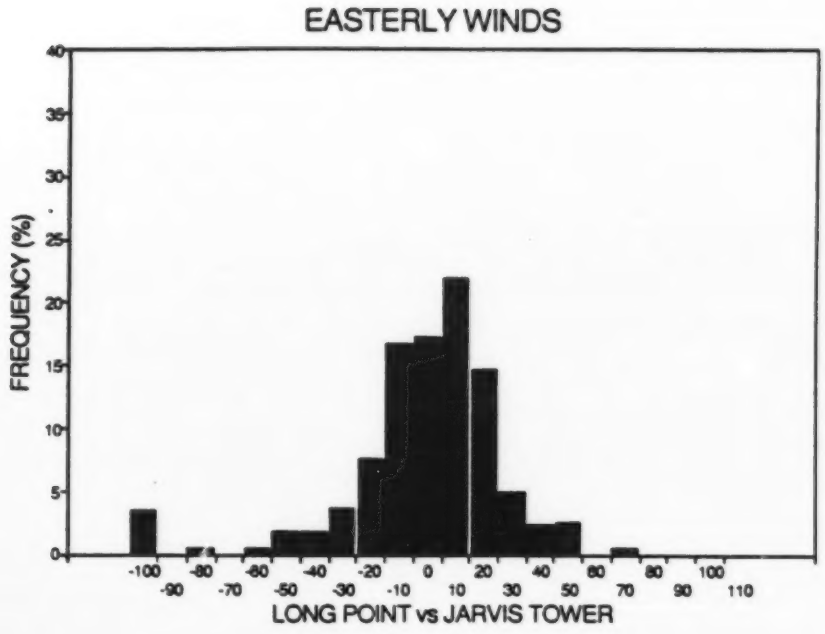
Histograms of wind direction differences
grouped by wind direction category

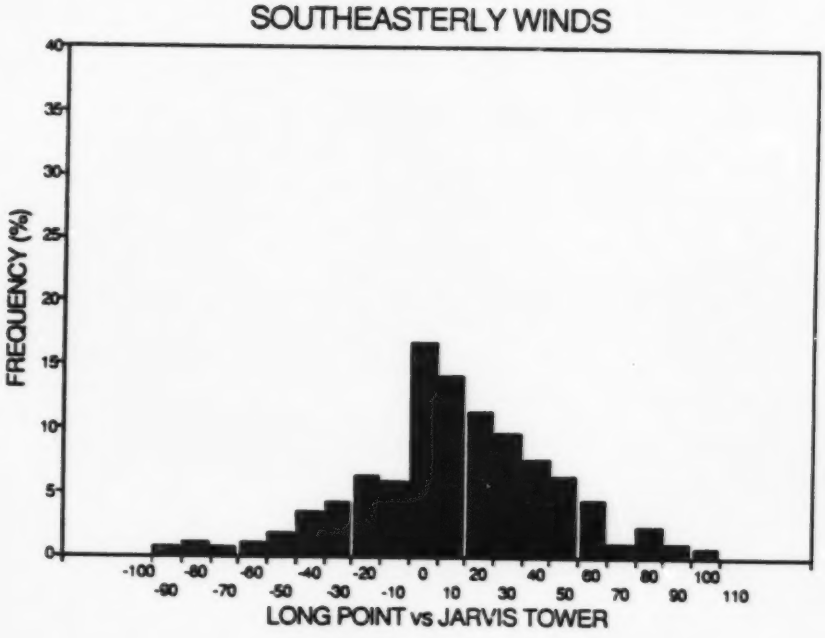
NORTHERLY WINDS



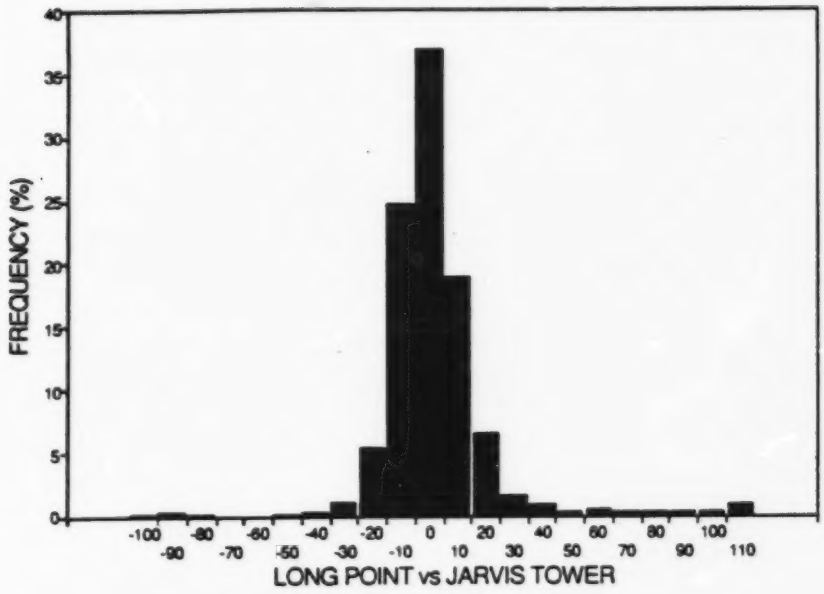
NORTHEASTERLY WINDS



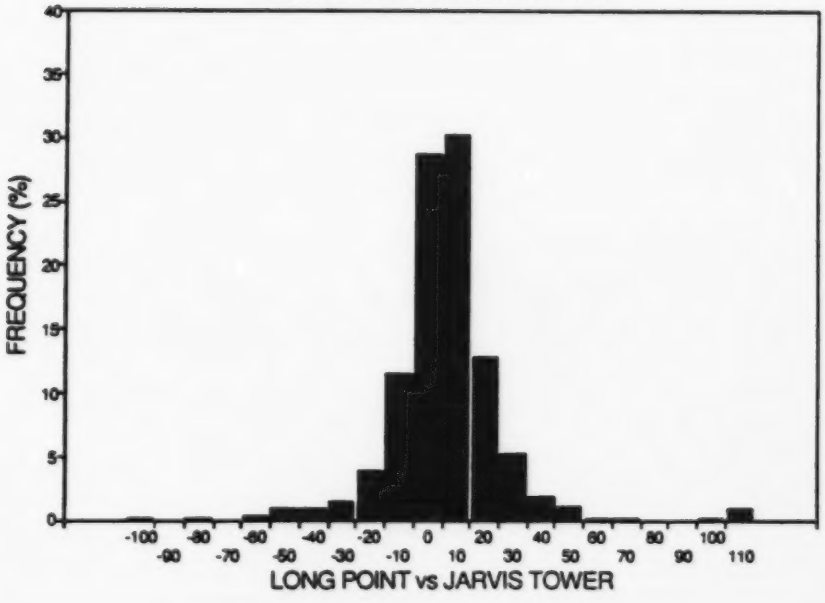

EASTERLY WINDS
FREQUENCY (%)
0
5
10
15
20
25
30
35
40
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110
LONG POINT vs JARVIS TOWER

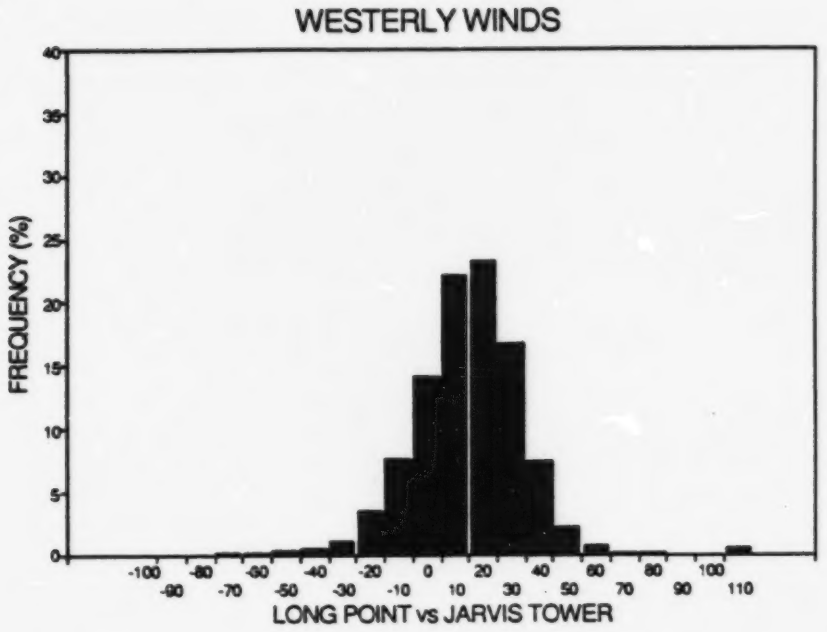

SOUTHEASTERLY WINDS
FREQUENCY (%)
0
5
10
15
20
25
30
35
40
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110
LONG POINT vs JARVIS TOWER

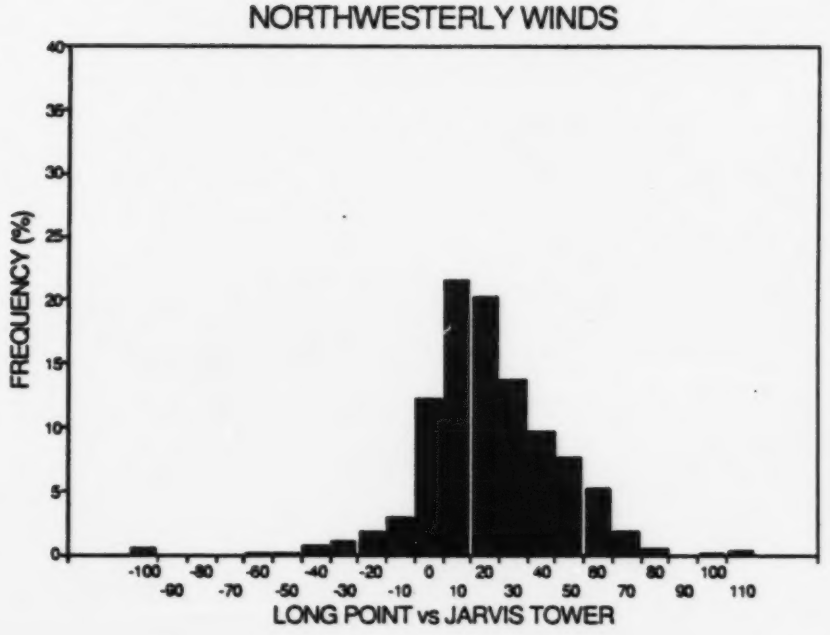
SOUTHERLY WINDS



SOUTHWESTERLY WINDS

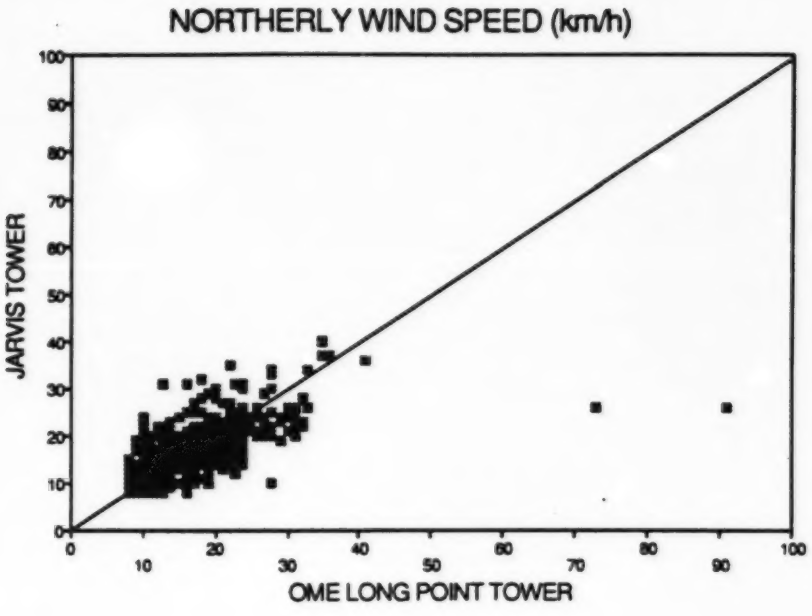



WESTERLY WINDS
FREQUENCY (%)
0
5
10
15
20
25
30
35
40
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110
LONG POINT vs JARVIS TOWER

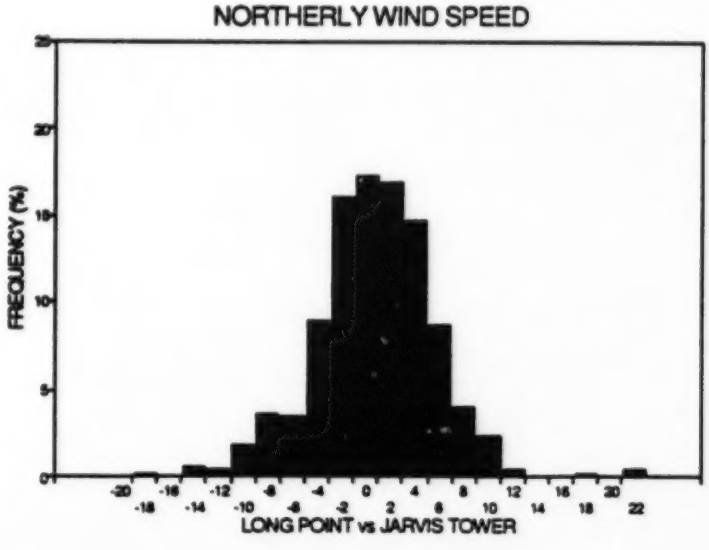

NORTHWESTERLY WINDS
FREQUENCY (%)
0
5
10
15
20
25
30
35
40
-100 -90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90 100 110
LONG POINT vs JARVIS TOWER

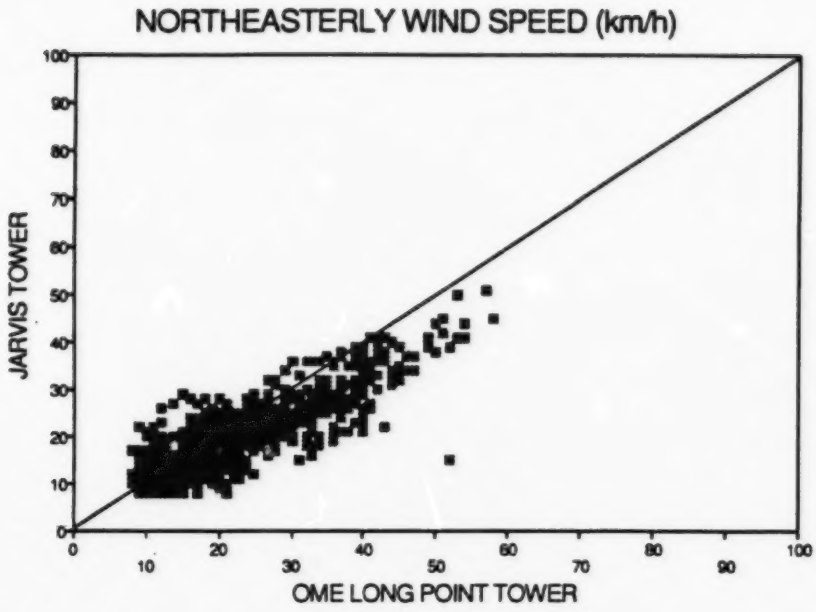
Appendix B

Linear Regression and histograms of wind speed
grouped by wind direction category



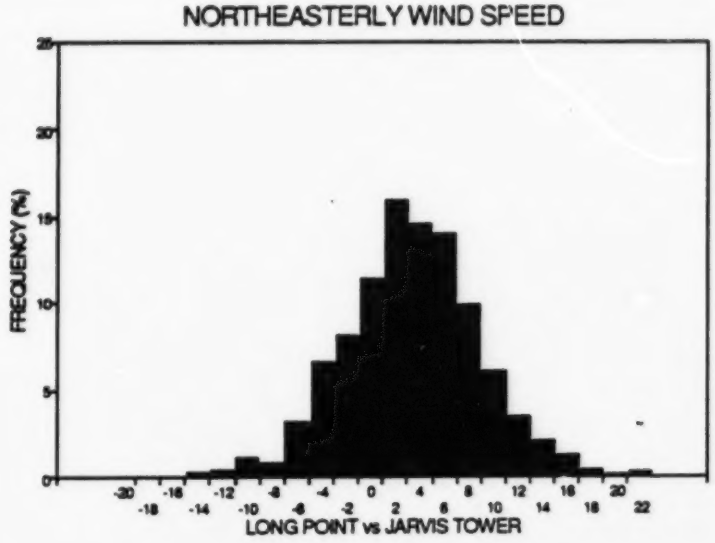
Regression Output:		Regression Output:	
Constant	4.143567	Constant	0
Std Err of Y Est	5.755353	Std Err of Y Est	5.897327
R Squared	0.363603	R Squared	0.330469
No. of Observations	497	No. of Observations	497
Degrees of Freedom	495	Degrees of Freedom	496
X Coefficient(s)	0.771536	X Coefficient(s)	0.992486
Std Err of Coef.	0.045878	Std Err of Coef.	0.014869



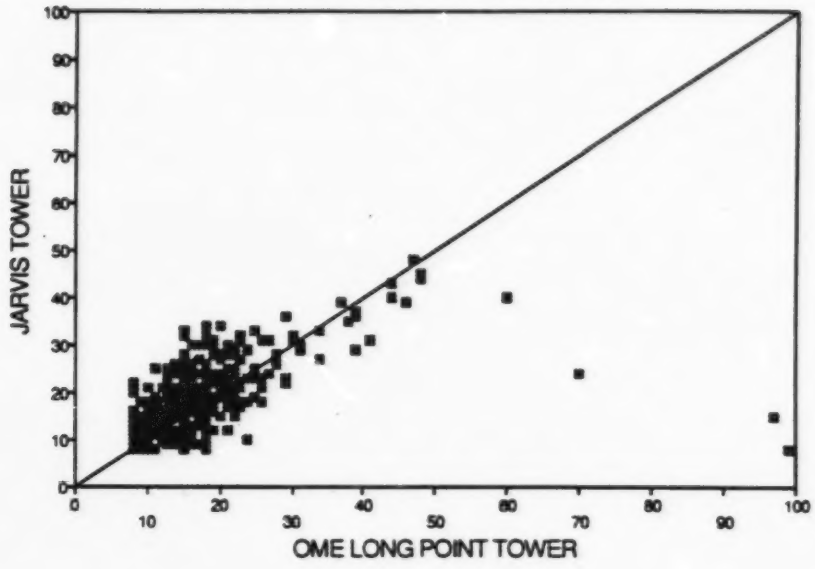


Regression Output:	
Constant	2.142023
Std Err of Y Est	5.574657
R Squared	0.690382
No. of Observations	745
Degrees of Freedom	743
X Coefficient(s)	1.034082
Std Err of Coef.	0.025406

Regression Output:	
Constant	0
Std Err of Y Est	5.625662
R Squared	0.684267
No. of Observations	745
Degrees of Freedom	744
X Coefficient(s)	1.124685
Std Err of Coef.	0.009365



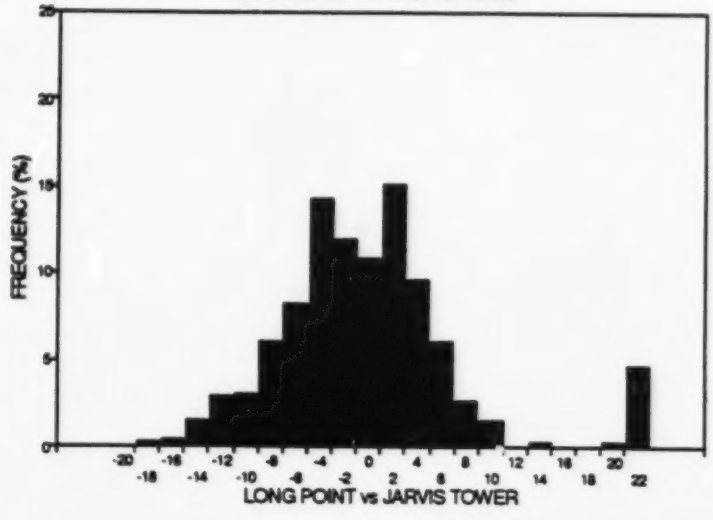
EASTERLY WIND SPEED (km/h)

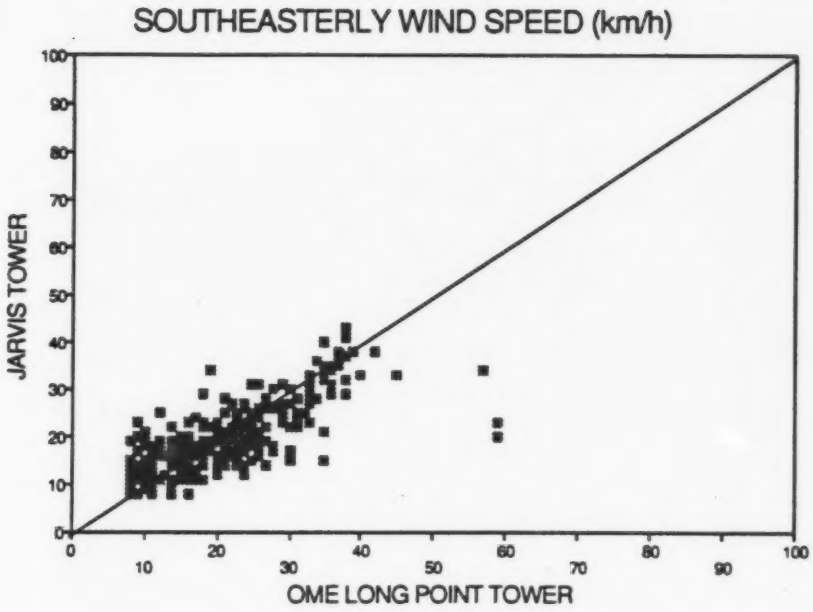


Regression Output:		
Constant		-4.15634
Std Err of Y Est		20.15137
R Squared		0.211355
No. of Observations		384
Degrees of Freedom		382
X Coefficient(s)	1.33751	
Std Err of Coef.	0.13219	

Regression Output:		
Constant		0
Std Err of Y Est		20.18373
R Squared		0.206749
No. of Observations		384
Degrees of Freedom		383
X Coefficient(s)	1.154038	
Std Err of Coef.	0.048931	

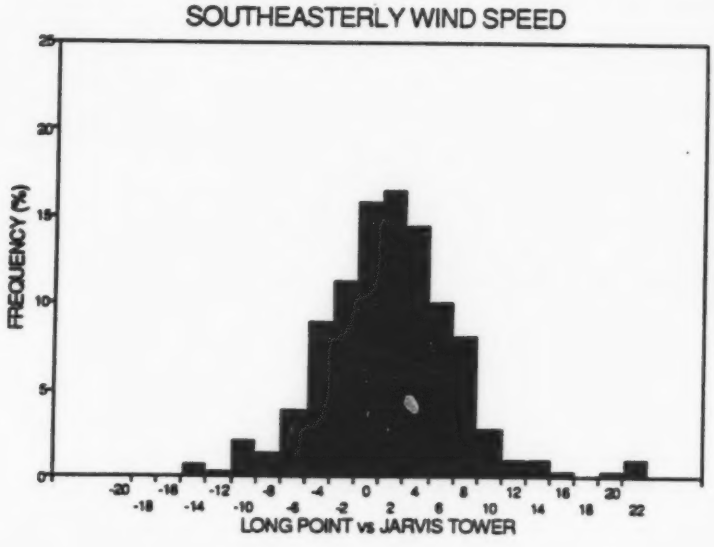
EASTERLY WIND SPEED

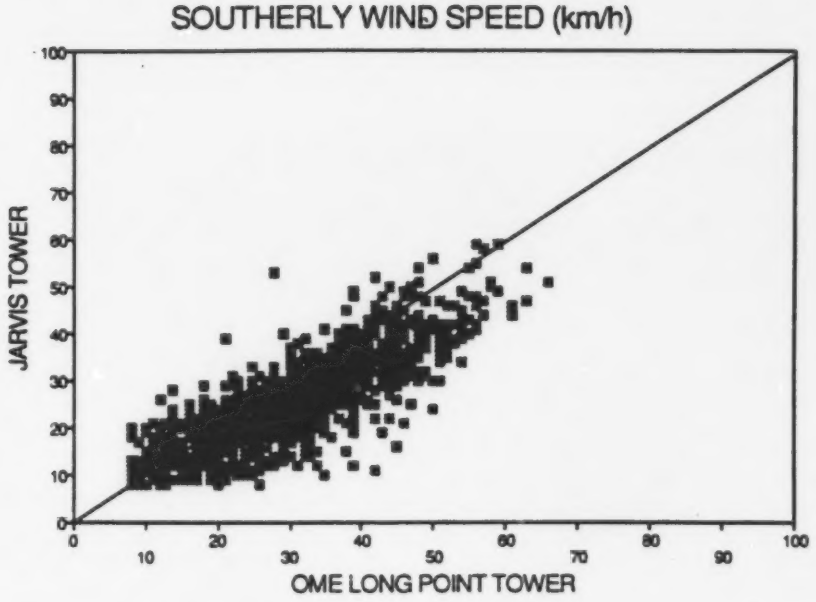




Regression Output:	
Constant	2.214939
Std Err of Y Est	6.102086
R Squared	0.548154
No. of Observations	291
Degrees of Freedom	289
X Coefficient(s)	0.957221
Std Err of Coef.	0.051122

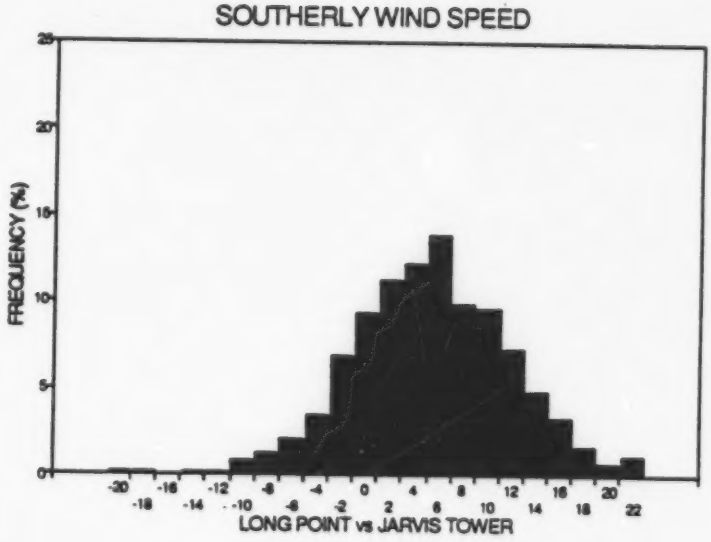
Regression Output:	
Constant	0
Std Err of Y Est	6.138221
R Squared	0.541205
No. of Observations	291
Degrees of Freedom	290
X Coefficient(s)	1.058559
Std Err of Coef.	0.017509

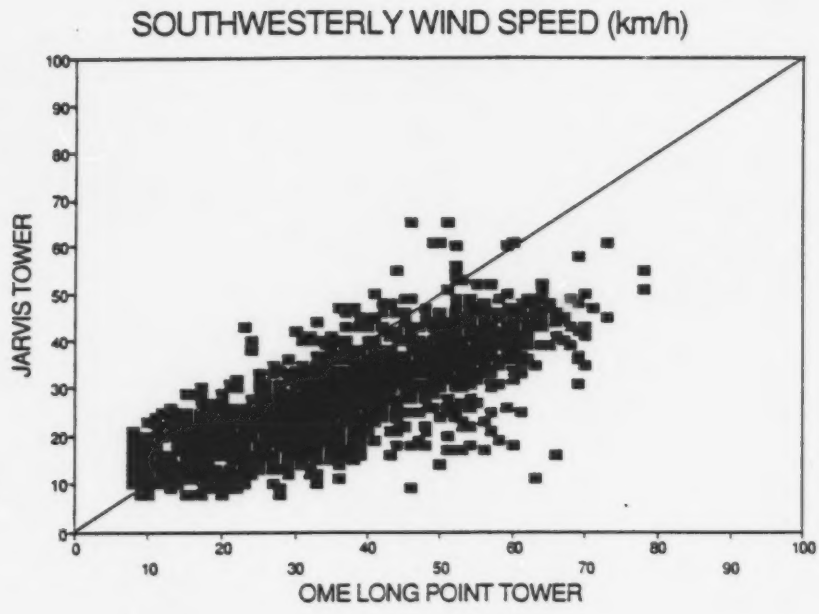




Regression Output:	
Constant	4.261784
Std Err of Y Est	5.523263
R Squared	0.674355
No. of Observations	1198
Degrees of Freedom	1196
X Coefficient(s)	0.706035
Std Err of Coef.	0.014187

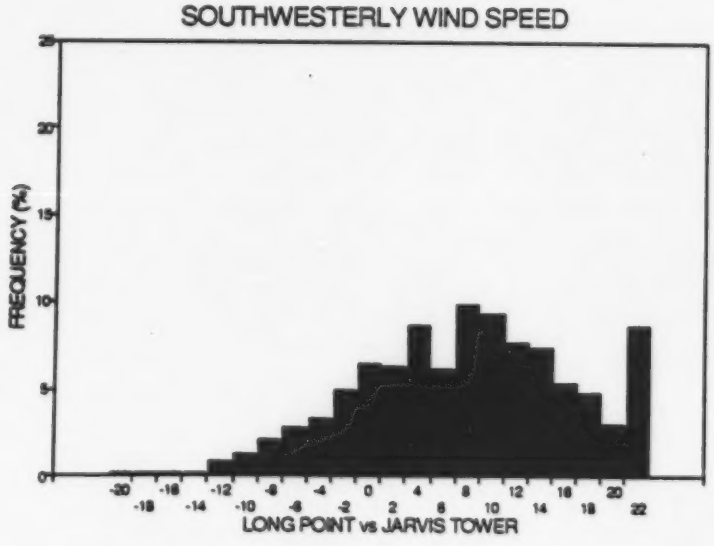
Regression Output:	
Constant	0
Std Err of Y Est	5.705155
R Squared	0.652263
No. of Observations	1198
Degrees of Freedom	1197
X Coefficient(s)	0.826338
Std Err of Coef.	0.004942



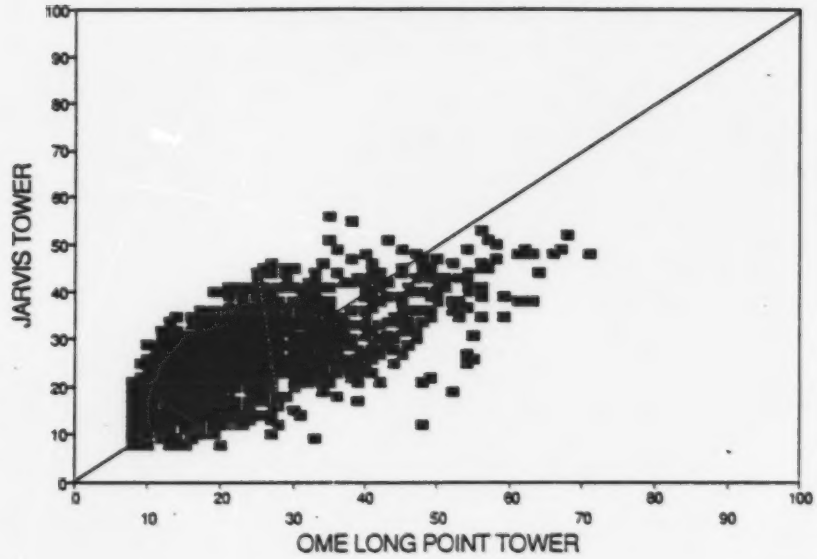


Regression Output:	
Constant	8.808271
Std Err of Y Est	6.69461
R Squared	0.563623
No. of Observations	1524
Degrees of Freedom	1522
X Coefficient(s)	0.53392
Std Err of Coef.	0.012042

Regression Output:	
Constant	0
Std Err of Y Est	7.44006
R Squared	0.460677
No. of Observations	1524
Degrees of Freedom	1523
X Coefficient(s)	0.74601
Std Err of Coef.	0.004937



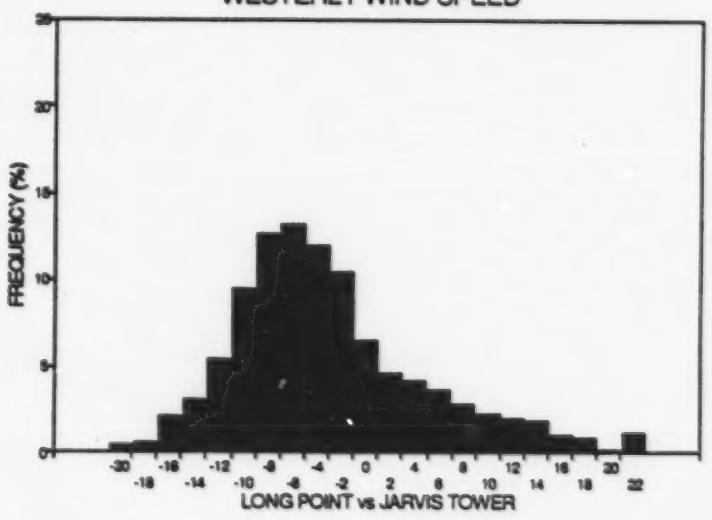
WESTERLY WIND SPEED (km/h)



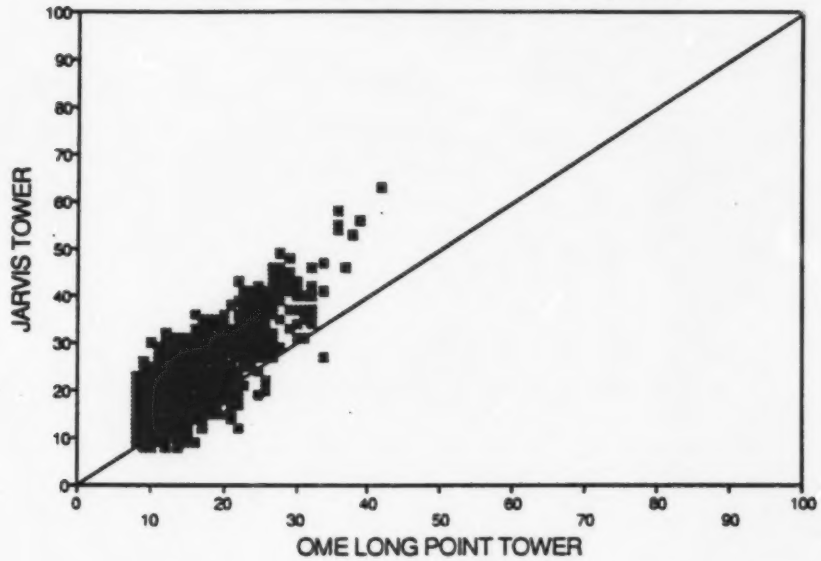
Regression Output:	
Constant	14.97239
Std Err of Y Est	5.967442
R Squared	0.428702
No. of Observations	1753
Degrees of Freedom	1751
X Coefficient(s)	0.49031
Std Err of Coef.	0.013526

Regression Output:	
Constant	0
Std Err of Y Est	8.715138
R Squared	-0.21922
No. of Observations	1753
Degrees of Freedom	1752
X Coefficient(s)	1.03616
Std Err of Coef.	0.00838

WESTERLY WIND SPEED



NORTHWESTERLY WIND SPEED (km/h)



Regression Output:	
Constant	6.218321
Std Err of Y Est	5.198733
R Squared	0.583818
No. of Observations	1135
Degrees of Freedom	1133
X Coefficient(s)	1.062006
Std Err of Coef.	0.026639

Regression Output:	
Constant	0
Std Err of Y Est	5.61006
R Squared	0.514927
No. of Observations	1135
Degrees of Freedom	1134
X Coefficient(s)	1.405104
Std Err of Coef.	0.009769

NORTHWESTERLY WIND SPEED